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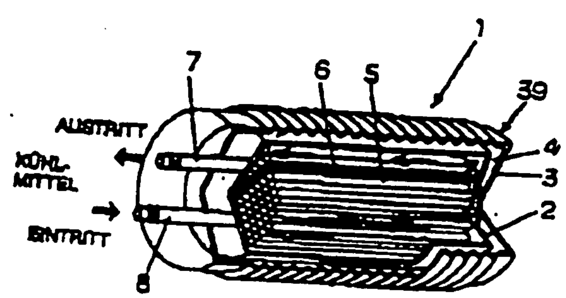
Translation

(54) Wärmespeicher mit Rührfunktion

(57) Es wird eine Phasenabscheidung eines Salzhydrats als Wärmespeichermedium (9) verhindert, wodurch die Wärmespeicherdichte eines Wärmespeichers (1) für eine lange Zeitspanne aufrechterhalten wird. Ein Wärmespeicherrohr (5) enthält $Ba(OH)_2 \cdot 8H_2O$ als Wärmespeichermedium (9), das keiner Unterkühlung ausgesetzt wird, und eine Kugel (10) ist im Wärmespeicherrohr (5) bewegbar. Ein Wärmeisoliergefäß (39) mit einem Kühlwasser-Einlaßrohr (8) und einem Kühlwasser-Auslaßrohr (7) ist mit Wärmespeicherrohren (5) aufgefüllt. Durch Vibrierenlassen des mit einer Rührfunktion ausgestatteten Wärmespeichers (1), der die Wärmespeicherrohre (5) und das Wärmeisoliergefäß (39) umfaßt, bewegt sich die Kugel (10) im Wärmespeicherrohr (5), um das Wärmespeichermedium (9) zu rühren, so daß die Verteilung von Wasser gleichmäßig wird und eine Phasenabscheidung verhindert wird.



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Die folgenden Angaben sind den vom Anmelder eingereichten Unterlagen entnommen

ZEICHNUNGEN SEITE 1

Nummer: E 196 19 818 A1
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FIG. 1

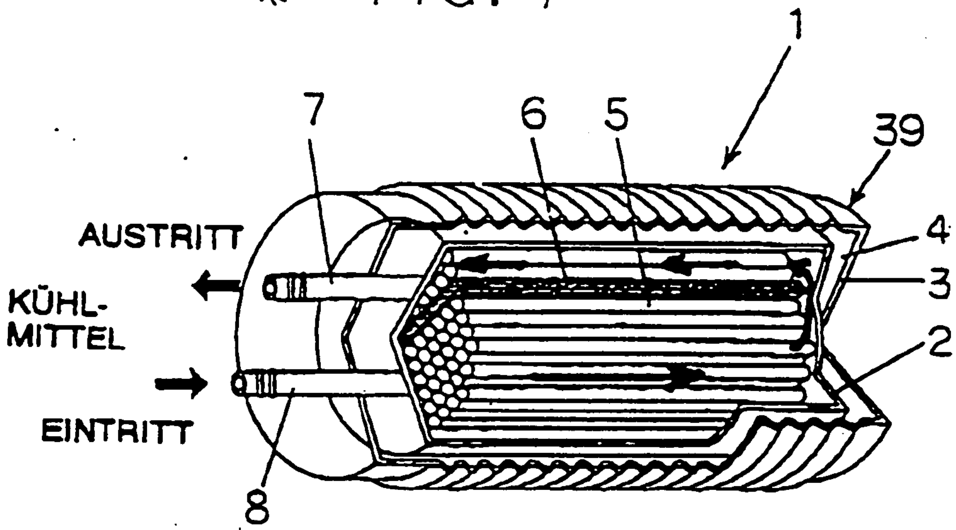

FIG. 2

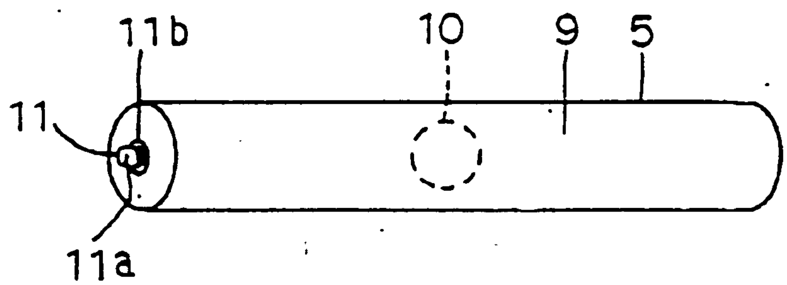

FIG. 3

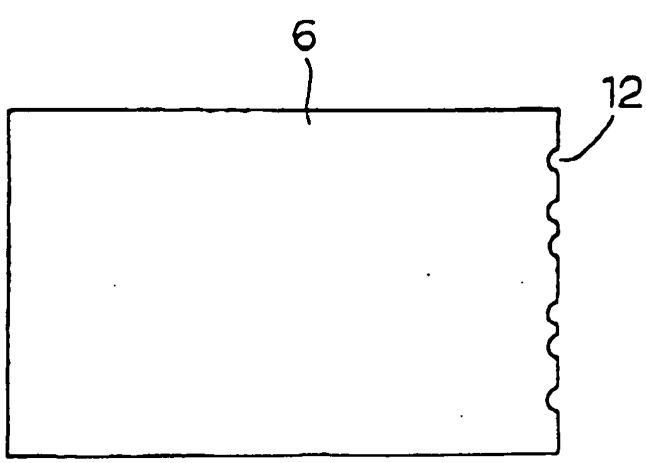

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FIG. 5

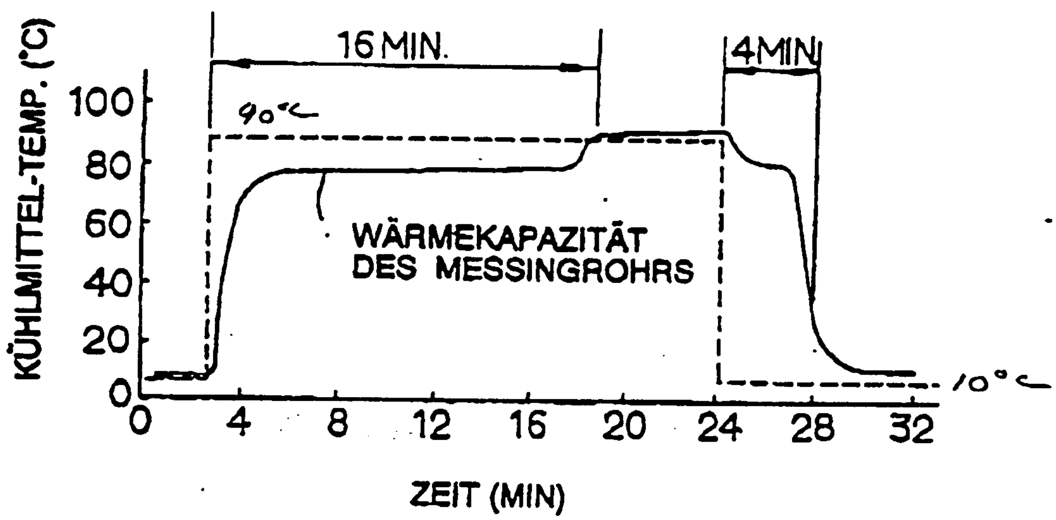

FIG. 6

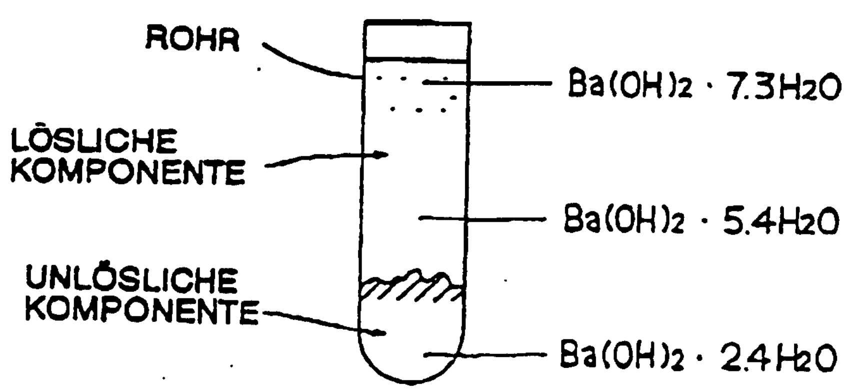

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FIG. 7

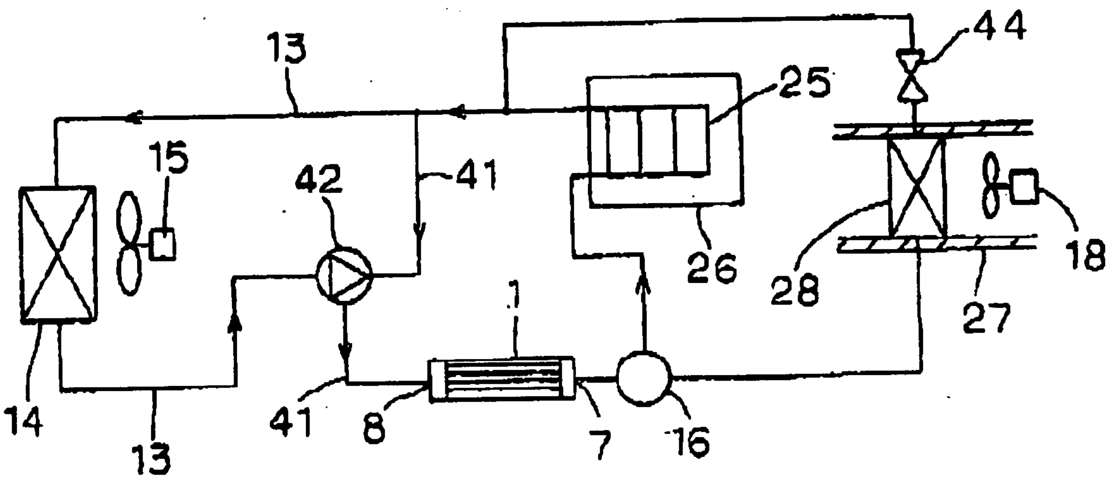

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FIG. 8

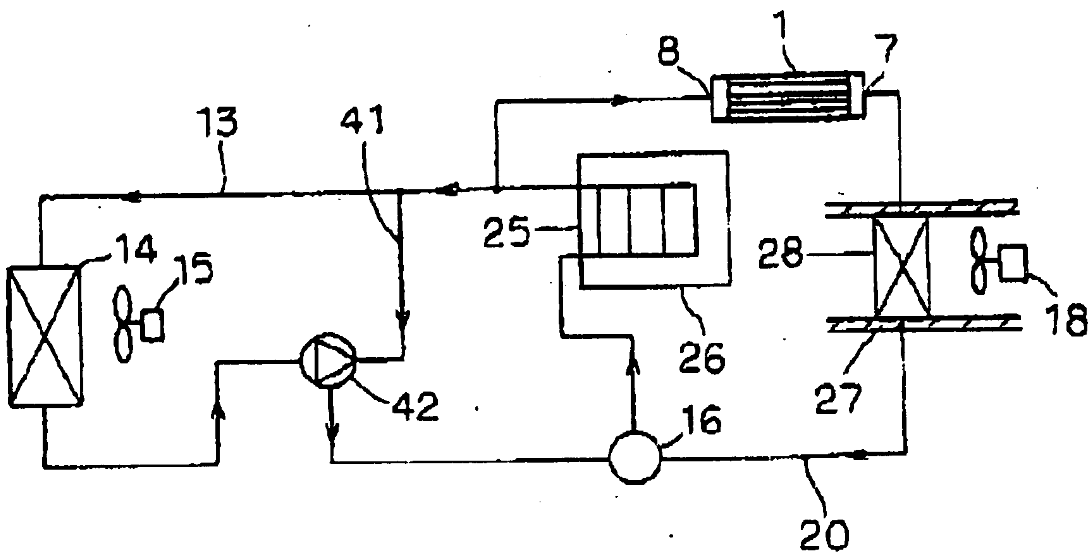

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FIG. 9

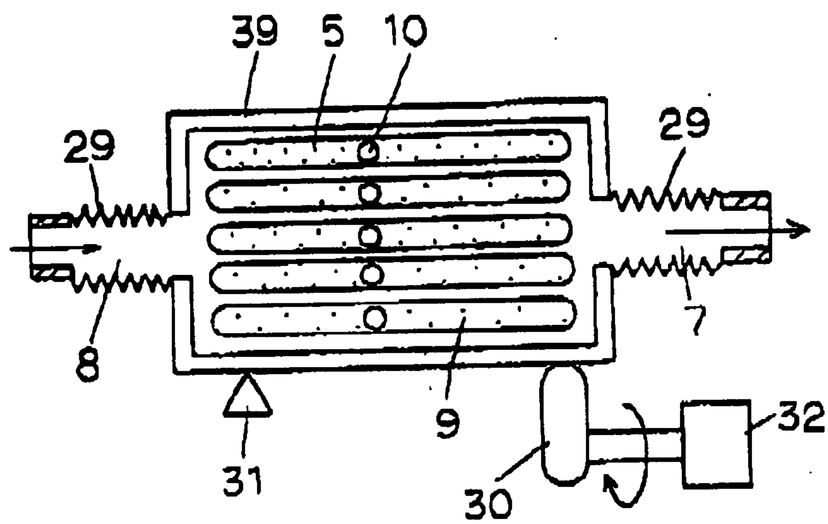

FIG. 10

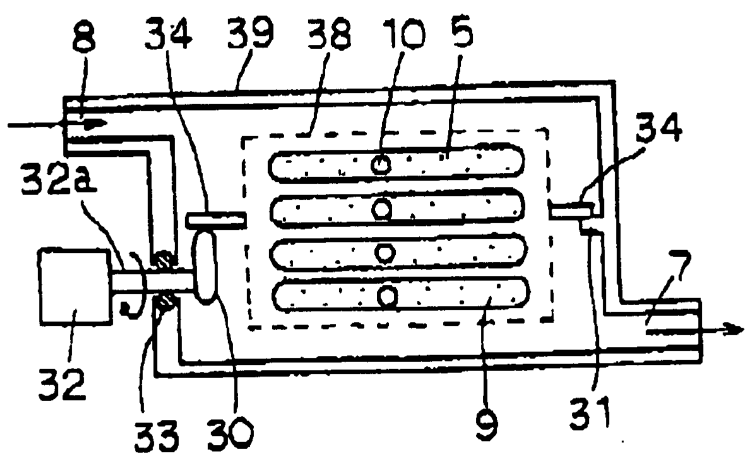

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FIG. 11

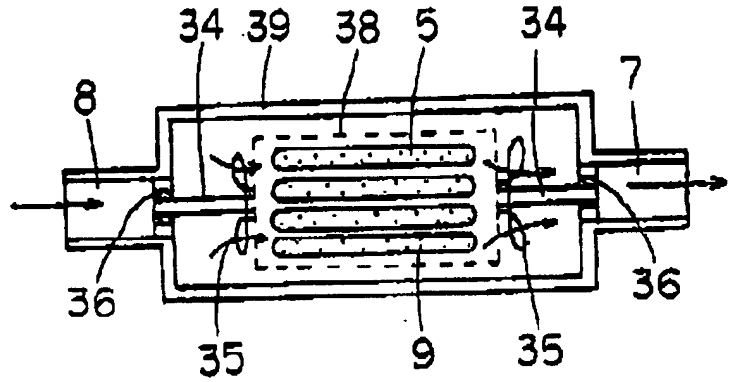

FIG. 12

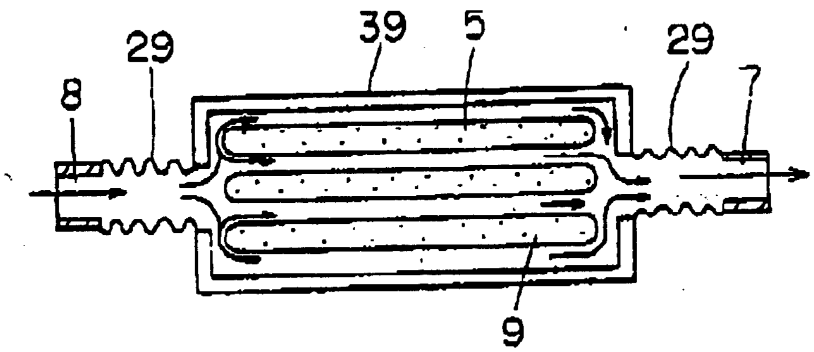

FIG. 13

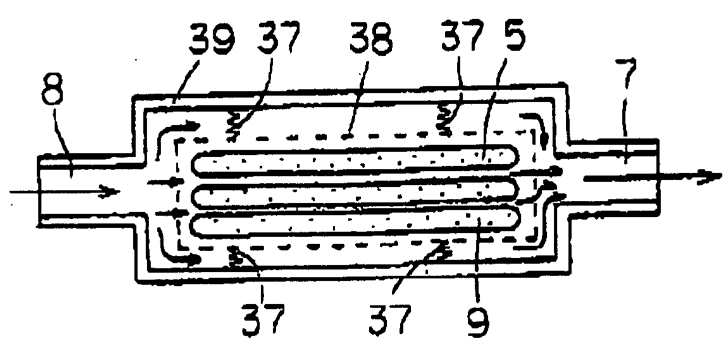

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FIG. 14

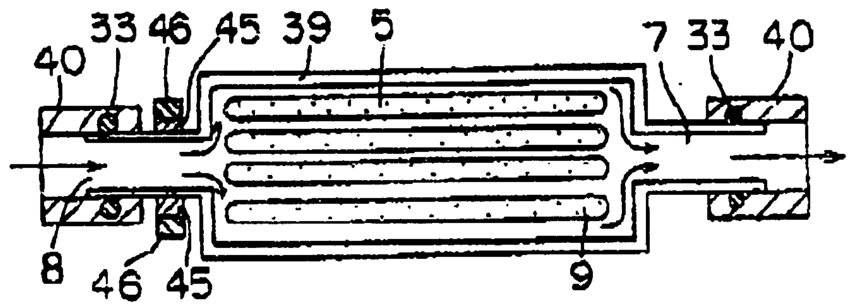

FIG. 15

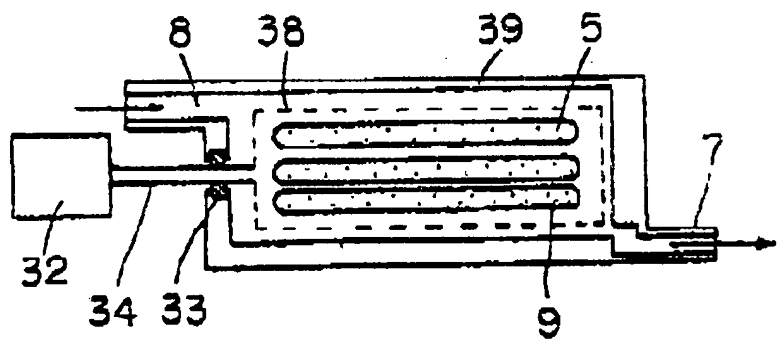

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FIG. 16

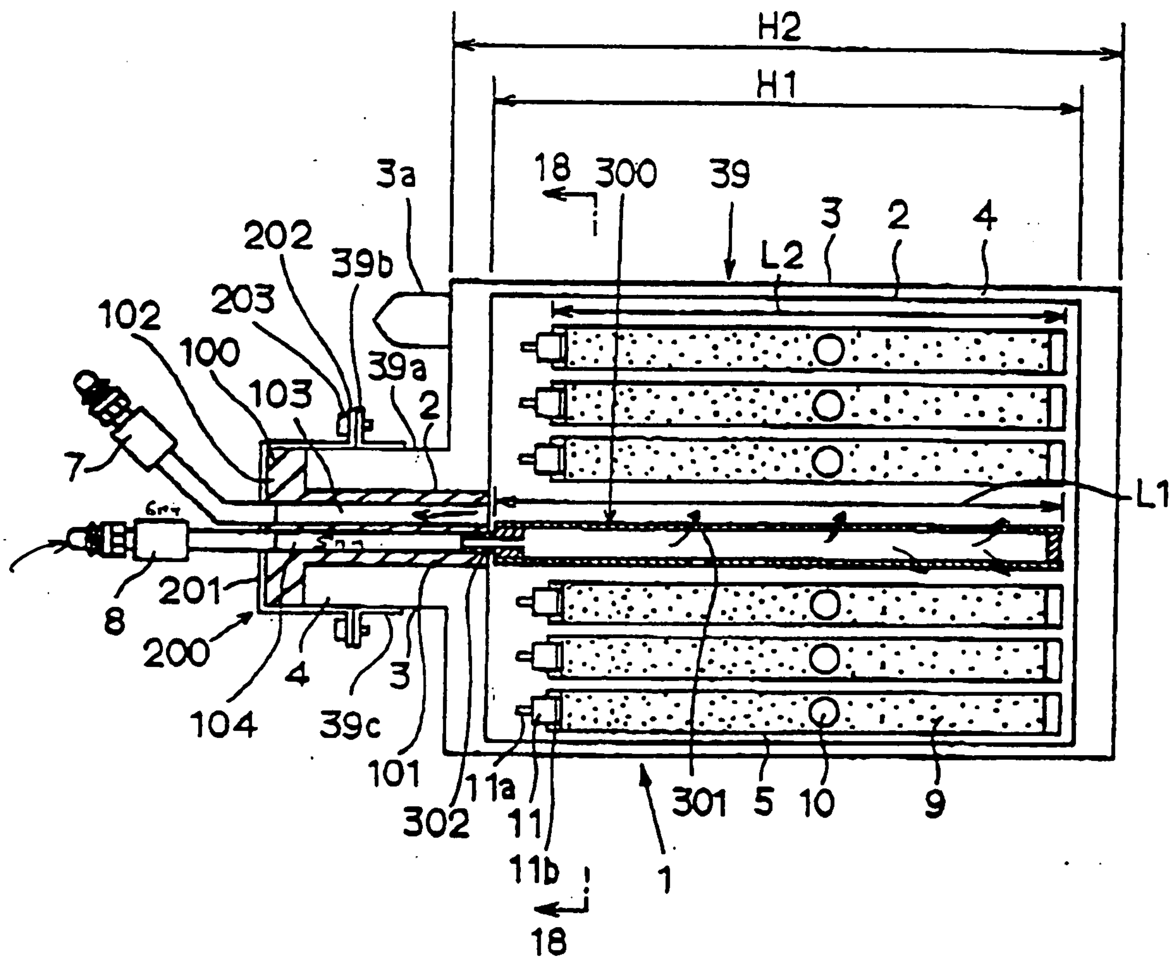

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FIG. 17

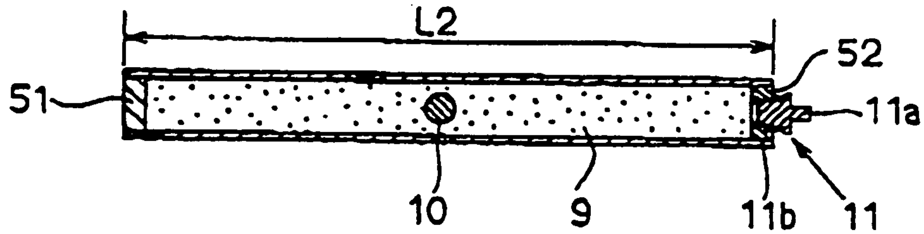

FIG. 18A

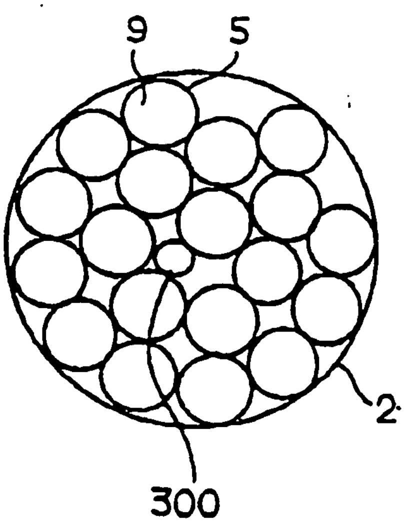

FIG. 18B

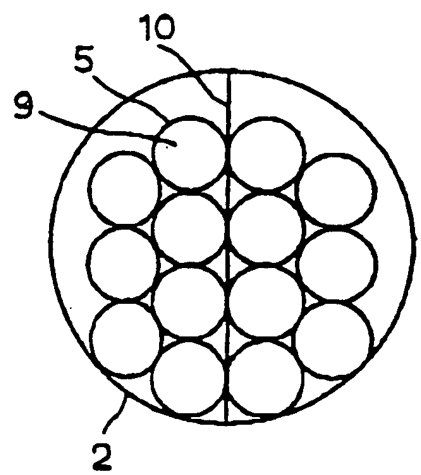

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FIG. 19A

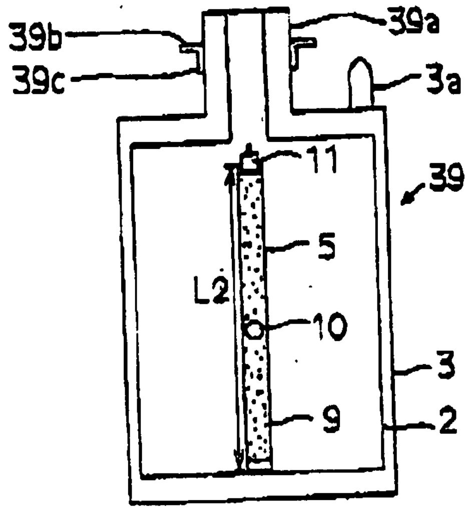


FIG. 19B

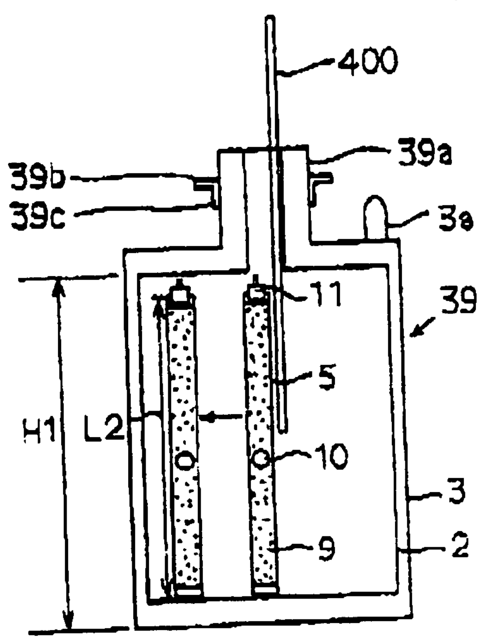
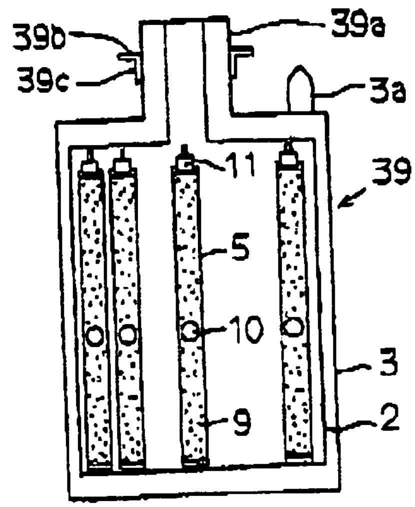


FIG. 19C



Translator's note:
The translation does not match the formatting of the original. To assist in cross-referencing, the beginning of each column (2 per page, 1-19) of the original is referenced in the translation as follows: [column X]

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64. Heat accumulator with agitation

57. A salt hydrate serving as heat storage medium (9) is prevented from undergoing a phase separation, which permits the heat storage density of a heat accumulator (1) to be maintained for a long period of time. A heat storage pipe (5) contains $Ba(OH)_2 \cdot 8H_2O$ as heat storage medium (8), which is not subject to supercooling, and a ball (10) which is movable in the heat storage pipe (5). A thermal insulation container (39) with a cooling water inlet pipe (8) and a cooling water outlet pipe (7) is filled with heat storage pipes (5). By setting up vibrations in the heat accumulator (1), which contains heat storage pipes (5) and the thermal insulation container (39) and is equipped with an agitator, the ball (10) moves in the heat storage pipe (5) so as to agitate the heat storage medium (9) and thus provide for a uniform distribution of water and prevent a phase separation.

[Key to drawing]
1. Outflow
2. Coolant
3. Influx

Specification

The invention concerns a heat accumulator which makes use of the latent heat associated with the liquefaction and solidification of a salt hydrate and which can be effectively utilized for a quick-acting heater for a motor vehicle, a quick-acting defroster, a motor oil heater, a hot water supply device for use in the home, and similar devices.

A heat accumulator that makes use of latent heat and utilizes heat absorption and emission processes associated with a change of phase or state of a salt hydrate, such as liquefaction, solidification or similar changes, was suggested in DE-A1-42 44 465.

In technical application, $Ba(OH)_2 \cdot 8H_2O$, a salt hydrate that induces no supercooling, is used as heat accumulator medium. In its solid phase, $Ba(OH)_2 \cdot 8H_2O$ absorbs latent heat from outside and liquifies when the melting point is reached. When it solidifies from the liquid phase, the absorbed latent heat, for example 70 cal/g, is released or emitted to the outside.

A large amount of latent heat is obtained through use of such a heat accumulator medium, and when the latent heat absorbed from outside is stored in a heat storage medium, and the heat is then released as needed, it can be utilized in an effective manner for a quick-acting heater for a motor vehicle, a quick-acting defroster, a quick-acting seat heating unit, a motor oil heater, a hot water supply device for use in the home, and similar devices.

When the water distribution at the time of liquefaction is not uniform, a phase separation occurs in which an unmelted, heat-resistant crystal of high density is deposited at a temperature equal to or above the melting point. Since a quantity of heat of fusion corresponding to that of the deposited crystal cannot be absorbed, the heat storage density of the heat accumulator is reduced. In order to prevent the phase separation by, for example, distributing the water that is formed at the time of liquefaction uniformly, the heat accumulator medium can be mixed with a hydrophilic polysaccharide or similar substance, such as xanthan gum, as thickening agent (see for example the disclosed Japanese patent publication 59-53 578).

For a heat accumulator in which the heat storage medium includes a salt hydrate that is contained or housed in a heat storage container, the distribution of water formation at the time of liquefaction changes, even when a thickening agent has been added, and the unmelted, heat-resistant crystal of high density is deposited, even at a temperature equal to or above the melting point, while the heat storage medium repeats the liquefaction and solidification processes. In addition, when such a crystal is present it becomes a grain, and the unmelted, heat-resistant crystal grows while the liquefaction and solidification processes are repeated. Therefore, a quantity of latent heat corresponding to that of the crystal cannot be absorbed, and the

[column 2] heat storage density of the heat accumulator is reduced.

Since the detectable heat of the thickening agent is less than the latent heat of the heat storage medium, the heat storage density of the heat accumulator is reduced by a quantity corresponding to the thickening agent when the thickening agent is added.

In view of the problems described above, one goal of the invention is to create a heat accumulator in which the distribution of water that is formed when the heat storage medium melts is uniform without addition of a thickening agent, and unmelted, heat-resistant crystals of high density are not allowed to deposit at a temperature equal to or above the melting point, even when the liquefaction and solidification processes are repeated, whereby it becomes possible to maintain the heat storage density of the heat accumulator over a long period of time.

The aforementioned goal is achieved in a first preferred embodiment of the invention which provides a heat storage medium of one phase, which changes in a reversible manner between a liquid phase and a solid phase in connection with absorption and emission of latent heat, and an agitator that agitates the storage medium. The heat storage container is situated in a thermal insulation container. The thermal insulation container also holds a heat transfer medium.

When the heat transfer medium, at a temperature equal to or above the melting point of the heat storage medium, is put into circulation through an inlet and an outlet in the thermal insulation container, the heat storage medium absorbs latent heat from the heat transfer medium and liquifies. Since the thermal insulation container blocks the outflow and influx of heat, the latent heat is stored in the heat storage medium. When the heat transfer medium, at a temperature below the melting point of the heat transfer medium, is put into circulation in the thermal insulation container through the inlet and the outlet, the stored latent heat is transferred to the heat transfer medium and the heat storage medium solidifies.

Since the heat storage medium can be agitated by the agitator during the step in which the heat storage medium absorbs the latent heat and liquifies, the distribution of water that is formed when the heat storage medium melts is uniform, thus preventing the formation of an unmelted, heat-resistant crystal of high density at a temperature equal to or above the melting point. Moreover, the growth of an unmelted, heat-resistant crystal resulting from the repeated liquefaction and solidification processes can be delayed. Since all of the latent heat, including a quantity corresponding to that of the crystal, can be absorbed, the heat storage density of the heat accumulator can be maintained for a long period of time without addition of a thickening agent.

In a preferred design, the device has a movable ball as agitator in the heat storage container,

[column 3] where the ball can move in the heat storage container so as to agitate the heat storage medium.

The ball can be moved freely in the heat storage container by the vibration, for example, of the moving motor vehicle, so that the heat storage medium can be agitated in the heat storage container without use of a drive specially dedicated to this purpose, such as a motor or similar drive. The costs for such a specially dedicated drive are thus saved, and the design is simplified.

The heat storage container may also be induced to vibrate or turn by means of a drive external to the heat storage container in the form of an agitator. Since the use of a drive ensures a regular agitation process, the heat storage medium may be agitated reliably in the heat storage container.

The heat storage container may also have a pipe whose one end receives the heat transfer medium through the inlet, where the pipe has holes in its wall and the heat transfer medium flows out of the pipe into the thermal insulation container. Thus the heat transfer medium flowing out of the holes is put into circulation in the thermal insulation container, whereby heat is exchanged with the heat storage medium in the heat storage container.

In addition, the insulation container can have a single opening; since the inlet and the outlet communicate with the opening, the thermal insulation efficiency of the thermal insulation container can be improved.

The device can also have a hot-water supply source for delivery of hot water, which serves as heat transfer medium, and a thermal radiator that provides for a heat exchange between the hot water supplied by the heat accumulator and by the hot water supply source and air, so as to heat up the volume contained therein. The hot water is put into circulation via a first circuit from the hot water supply source to the heat exchanger for heating via the thermal insulation container. The hot water is put into circulation via a second circuit from the thermal insulation container to the heat exchanger for heating.

When the hot water, at a temperature equal to the melting point of the storage medium or above the same temperature of the hot water supply source, is put into circulation via the first circuit from the hot water supply source to the thermal insulation container, the heat storage medium liquifies from its solid state through absorption of the latent heat of the hot water, and since the outflow and influx of heat is blocked by the thermal insulation container, the latent heat is stored in the heat storage medium.

When the hot water, at a temperature below the melting point of the heat storage medium, is put into circulation via the second circuit from the inlet, the thermal radiator and the thermal insulation container to the outlet, the stored latent heat is transferred to the hot water, so that the heat storage medium solidifies from its liquid state and the hot water is heated. The heated hot water undergoes a heat exchange with air by means of the thermal radiator, thus permitting

[column 4] the passenger compartment to be heated.

The heat transfer medium can be the motor cooling water of a

motor vehicle engine, and the thermal radiator can be a heating unit for heating the passenger compartment of a vehicle.

When the motor cooling water, at a temperature below the melting point of the heat storage medium, is put into circulation via the second circuit from the thermal insulation container to the heating unit to heat the passenger compartment through the inlet and the outlet, the heat storage medium solidifies because the stored latent heat is transferred to the motor cooling water, thus heating the motor cooling water. Since a heat exchange takes place between the heated motor cooling water and the air by means of the heating unit so as to heat up the passenger compartment, the passenger compartment can be heated quickly even immediately after the vehicle's motor is started, at which point the motor cooling water has not been warmed yet.

When the motor cooling water, at a temperature below the melting point of the heat storage medium, is put into circulation through the inlet and the outlet via the first circuit from the motor of the vehicle to the heating unit via the thermal insulation container to heat the passenger compartment, the stored latent heat can furthermore be transferred to the motor cooling water, thus solidifying the heat storage medium and heating the motor cooling water. The warm-up time immediately after the start of the quick-acting heater for the passenger compartment and the start of the vehicle's motor can be reduced by means of the heated motor cooling water. The reduction in the vehicle motor's warm-up time can be expected to result in cleaner exhaust and improved fuel efficiency.

Additional goals and features of the invention shall be presented in the course of the following specification.

Additional goals and advantages of the invention are clearly visible in the following detailed description of preferred embodiments with reference to the attached drawings.

Figure 1 is a partially sectioned schematic view of a heat accumulator representing the first embodiment of the invention;

Figure 2 is a perspective view of the agitator of the first embodiment;

Figure 3 is a front view of the cooling water collector of the first embodiment;

Figure 4 is a system diagram of the motor coolant circuit of the first embodiment;

Figure 5 is a diagram of the liquefaction/solidification characteristic line of $Ba(OH)_2 \cdot 8H_2O$, which is contained in a brass heat storage pipe;

Figure 6 illustrates the distribution of $Ba(OH)_2 \cdot 8H_2O$ separated into phases;

Figure 7 is a system illustration of the second embodiment of the invention;

Figure 8 is a system illustration of the third embodiment of the invention;

Figure 9 is a cross-section of a fourth embodiment of the invention;

Figure 10 is a cross-section of a fifth embodiment of the invention;

Figure 11 is a cross-section of a sixth embodiment

[column 5] of the invention;

Figure 12 is a cross-section of a seventh embodiment of the invention;

Figure 13 is a cross-section of an eighth embodiment of the invention;

Figure 14 is a cross-section of a ninth embodiment of the invention;

Figure 15 is a cross-section of a tenth embodiment of the invention;

Figure 16 is a partially sectioned view of an eleventh embodiment of the invention;

Figure 17 is a partially sectioned view of the heat storage pipe of the eleventh embodiment;

Figure 18A is a cross-section of the thermal insulation container of the eleventh embodiment;

Figure 18B is a cross-section of the thermal insulation container of the first embodiment;

Figures 19A to 19C are schematic views of a procedure for assembling the heat accumulator of the eleventh embodiment;

Figures 20A to 20D are schematic diagrams of a procedure for assembling the heat accumulator of the eleventh embodiment; and

Figure 21 is a diagram illustrating the liquefaction-solidification line of $Ba(OH)_2 \cdot 8H_2O$ for the eleventh embodiment.

The embodiments of the invention are described below with reference to the drawings.

Figures 1 to 6 show a first embodiment of the invention in which the invention is installed in a quick-acting heater for a vehicle.

Figure 4 shows a heat accumulator 1 with an agitator, which is described below, a motor 25 with water cooling to drive a motor vehicle, a water cooling jacket 26 for the motor 25, a radiator 14 to cool the motor cooling water, a fan 15 for forced induction of air to the radiator 14, a water pump 16 driven by the motor, a bypass circuit 41 parallel to the radiator 14, and a thermostat 42 to regulate the flow of cooling water to the radiator 14 and to the bypass circuit 41.

Number 28 indicates a heating unit to warm air through heat exchange between the heated cooling water and air, which heating unit is installed in a conduit 27 of an air conditioning system. Number 17 designates an electrically driven water pump to feed motor cooling water to the heat accumulator 1, and number 18 designates a fan to draw air from the air conditioning system.

Number 20 indicates a first circuit by means of which the motor cooling water is put into circulation from the motor 25 to the heating unit 28 via the heat accumulator 1 with agitator. Number 19 indicates a second circuit by means of which the motor cooling water is put into circulation from the heat accumulator 1 with agitator to the heating unit 28. Number 13 indicates a third circuit by means of which the motor cooling water is put into circulation from the motor 25 to the radiator 14.

Number 50 designates a control circuit to regulate a quick-

acting heater for a motor vehicle in the embodiment; the control circuit also regulates water temperature sensors 23 and 24, solenoid pilot valves 21, 22, 43 and 44, the water pump 17 and the fan 18. When the driver

[column 6] turns on the switch 51 of a quick-acting heater on the control panel of an air conditioning system for a vehicle, the control circuit 50 begins to operate.

The design of the heat accumulator 1 is described with reference to Figures 1 to 3.

A cooling water collector 6 made of a corrosion-resistant metal is placed in a cylindrical inner container 2 that is made of a corrosion-resistant metal, for example stainless steel, in order to divide the inner container 2 into two compartments. In this embodiment, the inner container has an internal diameter of 100 mm and an internal capacity of 0.82 l. The cooling water collector 6 is thin, for example about 1 mm, so as to be easily accommodated and yet sturdy and tough. One end of the cooling water collector 6 and the base of the inner container 2 contain holes 12. Heat storage pipes 5, each equal in height to the internal height of the inner container 2, fill up the inner container 2, by means of which the heat storage pipes 5 are housed and fixed such that they cannot move in the inner container 2. Since the cross-section of each pipe 5 is circular, a path is formed between neighboring pipes 5 through which motor cooling water flows, as will be described further below.

The heat storage pipes 5 are made of a corrosion-resistant metal that has excellent thermal conductivity and can be machined easily, such as brass. The walls of the pipes 5 are thin, and the diameter of the pipes 5 is small, so that they will have excellent thermal conductivity while yet remaining rigid. In this embodiment, the diameter of the pipes measures 14 mm and the pipe walls are 0.5 mm thick. One end of the pipe 5 is completely sealed, while the other end has a tapped hole 11b. A ball 10 made of a corrosion-resistant metal is inserted in each pipe 5 through the tapped hole 11b, the pipe 5 is filled with liquefied heat storage medium 9, and the tapped hole 11b is closed off with a screw cap 11, which is made of a material such as brass.

Number 11a designates a wrench receptacle to which the screw cap 11 is attached. A salt hydrate is used as heat storage medium 9; the salt hydrate has a large latent heat and is completely liquefied when the motor cooling water is at the temperature of the stationary driving state, for example 90°C to 100°C, and is completely solid when the motor cooling water is at the temperature required for the hot air to heat the passenger compartment of the vehicle, for example 40°C to 60°C. $Ba(OH)_2 \cdot 8H_2O$, with a melting point of 78°C and a latent heat of 70 cal/g, is used in this embodiment. A material that undergoes supercooling, such that a phase change does not occur when it is cooled from the liquefied state to a temperature below the temperature of the phase change, and which does not change when subjected to an external jolt, is not to be used as a heat storage medium 9.

The ball 10 can move freely in the heat storage pipe 5. The ball 10 is to be of a size adequate to agitate the heat storage medium 9. In this embodiment, the diameter is

[column 7] preferably 7 mm, which is half the internal diameter of the heat storage pipe 5. The inner container 2, with a capacity of 0.82 l, contains the heat storage medium 9 with a capacity of 0.46 l, the storage pipes 5, each with a capacity of 0.06 l, and about 0.3 l of motor cooling water.

The inner container 2 is placed in the cylindrical outer container 3, which is made of a corrosion-resistant metal. A vacuum insulation layer 4 is situated between the outer container 3 and the inner container 2 so as to insulate against heat exchange with the exterior. The inner container 2, the outer container 3 and the vacuum insulation layer 4 comprise a thermal insulation container 39 to prevent heat exchange with the exterior. A motor cooling water inlet pipe 8 and a motor cooling water outlet pipe 7, each made of a corrosion-resistant metal, are hermetically connected and sealed to one end of the inner container 2 and the outer container 3.

The heat accumulator 1 is installed in the motor compartment (not portrayed) of a motor vehicle in such a way that the heat storage pipes 5 run horizontal to the base, the motor cooling water inlet pipe 8 is located in the lower part of the motor compartment, and the motor cooling water outlet pipe 7 occupies a position in the upper part of the motor compartment. The motor cooling water flows from the lower part toward the upper part, and can execute a U-shaped curve in the thermal insulation container 39 by means of the cooling water collector 6. In addition, the flow volume of the motor cooling water is set according to the size of each of the holes 12 in the cooling water collector 6, which improves the efficiency of the heat exchange.

The operation of the first embodiment is described below.

When the motor 25 is started and the driver actuates the switch 51 of the quick-acting heater on the control panel of a vehicle's air conditioning system, first the control circuit 50 closes the solenoid pilot valves 21 and 22 and opens the solenoid pilot valves 43 and 44, so that motor cooling water, whose temperature is reduced to about the temperature of ambient air, flows to the heat accumulator 1 through the second circuit 19 by means of the water pump 17. Since the temperature of the motor cooling water is lower than the melting point of the heat storage medium 9, the heat storage medium 9 is cooled, solidifies, and stored latent heat is emitted. The motor cooling water in the inner container 2 is heated through the wall of the heat storage pipes 5, so that the temperature of the motor cooling water can be quickly raised.

When the heated motor cooling water is fed to the heating unit 28 by means of the water pump 17, the water undergoes a heat exchange with air whose temperature is roughly equal to that of ambient air, which is then conveyed by the fan 18, thus sending warm air into the passenger compartment. The motor cooling water is put into circulation via the second circuit 19, and the motor cooling water heated in the inner container 2 is continuously fed

to the heating unit 28. Since the warm air can be sent instantly into the passenger compartment even when the motor 25 is not sufficiently warmed, an operation such as that executed by a quick-acting heater for a vehicle can be carried out.

When such a quick-acting heater

[column 8] operates, the temperature of the motor 25 rises, and thus the temperature of the cooling water conveyed from the motor 25 also rises. The temperature T2 of the motor cooling water conveyed from the motor 25 is registered by a water temperature sensor 24, and the temperature T1 of the motor cooling water flowing into the heating unit 28 is registered by a water temperature sensor 23, and the temperature signals are sent to the control circuit 50. When the control circuit 50 determines that $T2 > T1$, the control circuit 50 opens the solenoid pilot valves 21, 22 and 44, closes the solenoid pilot valve 43, and stops the water pump 17. Thus part of the motor cooling water heated by the motor 25 flows through a branch A, the pilot valve 21, the water pump 17, the heat accumulator 1, the heating unit 28, the pilot valve 22, the first circuit 20, the water pump 16 and then to the motor 25, as indicated by the arrow. The function described above is a stationary heating operation, and the cooling water is fed from the motor 25 to the heating unit 28.

When the temperature of the motor cooling water lies below a preset temperature, a thermostat 42 opens the side of a bypass circuit 41, by means of which the cooling water can flow to the side of the bypass circuit 41. When the temperature of the cooling water rises further and becomes greater than or equal to the preset temperature, the thermostat 42 opens the side of the radiator 14 and closes the side of the bypass circuit 41. In this way, the motor cooling water heated by the motor 25 is cooled by the radiator 14 and put into circulation toward the heat accumulator 1 and the heating unit 28.

After the motor cooling water has flowed from the motor cooling water inlet pipe 8 into the inner container 2 and has passed through the cooling water collector 6, the motor cooling water flows out of the motor cooling water outlet pipe 7. When the temperature of the motor cooling water is 78°C or greater, the heat storage medium 9 absorbs the latent heat, and the phase of the heat storage medium 9 changes from solid to liquid. Since the ball 10 is induced to vibrate, rotate and move in three dimensions - that is, upward and downward, forward and backward, and to the left and the right - in connection with vibrations caused by the travel motion of the vehicle and vibrations set up when the vehicle turns to the right or left, stops or starts, the liquefied heat storage medium 9 is also agitated, and the distribution of water formed at the time of liquefaction is uniform, so that no unmelted, heat-resistant crystal of high density is formed at a temperature equal to or above the melting point. If the distribution of water is not uniform, the heat storage medium is split up into phases - an unmelted component $Ba(OH)_2 \cdot 2.4H_2O$ and dissolved components $Ba(OH)_2 \cdot 5.4H_2O$ and $Ba(OH)_2 \cdot 7.3H_2O$ - as illustrated in Figure 5.

After the motor is stopped, the latent heat absorbed by the motor cooling water is stored in the heat storage medium 9 because the outflow and influx of heat is blocked by the thermal insulation container. It is possible to repeat the process of turning on the switch 51 of the quick-acting heater after the motor has been started in order to start up the quick-acting heater again.

[column 9] Experimental tests of the heat absorption and heat emission properties and the associated characteristic line of the heat accumulator for this embodiment are described below with reference to Figure 5.

One of the heat storage pipes 5 with $Ba(OH)_2 \cdot 8H_2O$ as the heat storage medium 9 is used in the test. The diagram in Figure 5 shows the temperature (indicated by a solid line) of the heat storage medium 9 and the water temperature (indicated by a broken line) of a thermostatic device when the heat storage pipe 5, previously immersed in a thermostatic device at 10°C, is immersed in a thermostatic device at 90°C for approximately 22 minutes, and afterwards when the heat storage pipe 5 is again immersed in a thermostatic device set at 10°C for about 10 minutes.

From the diagram it is evident that when the heat storage pipe 5, which contains the heat storage medium 9 in a completely solid state, is immersed in the thermostatic device at 90°C, the heat storage medium 9 absorbs heat from the hot water, stores the latent heat, and is completely liquefied within about 16 minutes. Afterwards, when the heat storage pipe 5 is immersed in the thermostatic device at 10°C, the heat storage medium solidifies completely, in that the latent heat is transferred to the hot water within 4 minutes.

The properties of this rapid liquefaction and rapid solidification are suitable for use in a quick-acting heater for a motor vehicle. The inventor has confirmed that the quick-acting heater for a motor vehicle must emit heat within about 5 minutes after the motor is started, and this embodiment meets this requirement in an exceptional manner.

Figure 7 shows a second embodiment of the invention in which, as with the first embodiment, the heat exchanger 1 is placed in the circuit through which the cooling water flows from the radiator 14 to the motor 25. When the solenoid pilot valve 44 is closed by the sensor (not shown) and the control circuit is closed after the motor 25 is started, because the heated cooling water is fed only to the motor 25 by means of the water pump 16, all of the latent heat collected in the heat accumulator 1 can be utilized to shorten the warm-up time of the motor 25. Since the stored heat is not used for heating, the solenoid pilot valves 21, 22, 43, the temperature sensors 23 and 24, and the water pump are left out.

A third embodiment of the invention is shown in Figure 8. Since the heated cooling water is fed to the heating unit 28 and is made to flow directly to the motor 25 by means of the heat accumulator 1, the latent heat stored in the heat accumulator 1 is preferably used to heat the passenger compartment, and can also be

used to shorten the warm-up time. Since the stored latent heat is utilized only for heating, the solenoid pilot valves 21, 22, 43 and 44, the temperature sensors 23 and 24 and the water pump 17 of the first embodiment are removed.

The fourth to tenth embodiments described below concern modifications of the agitator for agitating the heat storage medium 9.

[column 10] In the fourth inventive embodiment shown in Figure 9, part of each motor cooling water inlet pipe 8 and each motor cooling water outlet pipe 7 consists of an elastically deformable bellows 29. One end of the lower part of the thermal insulation container 39 is supported by a cam 30 and the other end is supported by a support stanchion 31. The cam 30 is turned by a motor 32 that serves as a drive.

The heat accumulator 1 of this embodiment has a sensor (not shown) to register the temperature of the heat storage medium 9. When the sensor determines that the heat storage medium 9 is liquefied, a control circuit (not shown) starts up the motor 32. Through rotation of the cam 30 by means of the motor 32, one end of the thermal insulation container 39 is moved upwards and downwards, thus moving the ball 10 in the heat storage pipe 5, which agitates the heat storage medium 9.

In the fifth inventive embodiment, which is shown in Figure 10, number 38 designates a heat storage pipe stack made of a corrosion-resistant metal in a wire netting of such a kind that the heat transfer medium can flow freely forward and backward through it. Support rods 34 are furnished on both sides of the heat storage pipe stack 38, and the heat storage pipe stack 38 is filled with heat storage pipes 5. The cam 30, which can be turned by the motor 32, is deployed at a site that differs from the position of the motor cooling water inlet pipe 8 at one end of the thermal insulation container 39. The support stanchion 31 is situated at the other end within the thermal insulation container 39.

The heat storage pipe stack 38 is supported by the support stanchion 31 and the cam 30 in the thermal insulation container 39. The contact zone between the shaft 32a of the motor 32 and the thermal insulation container 39 is sealed by means of an O-ring 33, so that the heat transfer medium cannot leak out there. One end of the heat storage pipe stack 38 is moved in a vertical direction by the rotation of the cam 30 by means of the motor 32.

In the sixth inventive embodiment, which is shown in Figure 11, the support rods 34 are present at both ends of the heat storage pipe stack 38, and moving blades 35 are attached to the support rods 34. Bearings 36 for rotating support of the support rods 34 are located in the motor cooling water inlet pipe 8 and in the motor cooling water outlet pipe 7.

The rotating blades 35 are set in motion by the hydrodynamic force of the motor cooling water and the heat storage pipe stack 38 is thus turned, by means of which the heat storage medium 9 is agitated in the heat storage pipes 5.

In the seventh inventive embodiment, which is shown in Figure

12, part of the motor cooling water inlet pipe 8 and the motor cooling water outlet pipe 7 is designed in the form of a bellows 29. The device illustrated in Figure 12 is installed in a device with a vibration source, such as a motor vehicle, a motor or similar device.

The shaking of the motor vehicle, the motor and similar

[column 11] devices is intensified by each bellows 29 in order to shake the thermal insulation container 39, by means of which the heat storage medium 9 is agitated in the heat storage pipes 5.

In the eighth inventive embodiment, which is portrayed in Figure 13, the heat storage pipe stack 38 is attached elastically in the thermal insulation container 39 through installation of springs 37 within the thermal insulation container 39 and on the exterior of the heat storage pipe stack 38.

The shaking of the motor vehicle, the motor and similar devices is intensified by the spring 37, by means of which the thermal insulation container 39 can be shaken.

In the ninth inventive embodiment, which is shown in Figure 14, the motor cooling water inlet pipe 8 is hermetically connected to the center of one end of the thermal insulation container 39, and the motor cooling water outlet pipe 7 is hermetically sealed to the middle of the other end. The motor cooling water inlet pipe 8 and the motor cooling water outlet pipe 7 are pivoted with the help of fixed pipes. The contact zone is sealed by an O-ring 33 so that the motor cooling water does not escape. Pulleys 45 are attached to the exterior of the motor cooling water inlet pipe 8 and the motor cooling water outlet pipe 7. Each of the pulleys 45 has a belt 46 to apply a rotational force.

The thermal insulation container 39 is set in rotational motion by a motor (not shown) via the belt 46 in order to agitate the heat storage medium 9 in the heat storage pipes 5.

In the tenth inventive embodiment, which is shown in Figure 15, the support rod 34 is located at one end of the heat storage pipe stack 38, and the heat storage pipe stack 38 is set in rotational motion by the motor 32 via the support rod 34. Furthermore, the heat storage pipe stack 38 is deployed from one end of the thermal insulation container 38 through the support rod 34. The contact zone is sealed by means of the O-ring 33 so that cooling water cannot escape.

In the eleventh inventive embodiment, which is shown in Figure 16, the cooling water collector 6 of the aforementioned first embodiment is removed, its place taken by a permeable pipe 300. Although the motor cooling water outlet pipe 7 and the motor cooling water inlet pipe 8 are located at different places in the thermal insulation container 39 of the preceding first embodiment, in the eleventh embodiment only one pipe-shaped, protruding area 39a, projecting almost horizontally in pipe-shaped form from the left side of the thermal insulation container 39 from Figure 16, is connected to the thermal insulation container 39. The motor cooling water outlet pipe 7 and the motor cooling water inlet pipe 8 are intended for the pipe-shaped, protruding area 39a.

The pipe-shaped, protruding area 39a is used to connect the

interior and the exterior of the thermal insulation container 39. The pipe-shaped, protruding area 39a forms an opening in the thermal insulation container 39. The pipe-shaped, protruding area 39a is delimited by the inner container 2, the outer container 3 and the vacuum insulation layer 4. Number 3a in Figure 16 designates an air-mixing zone for mixing the air in the vacuum insulation layer 4 between the inner container 2 and the outer

[column 12] container 3.

A sealing cap 100 that is made of an elastic material with excellent heat resistance, excellent corrosion resistance and low thermal conductivity, such as silicone rubber, is pressed into the pipe-shaped, protruding area 39a and fixed in place. The motor cooling water outlet pipe 7 and the motor cooling water inlet pipe 8 are hermetically connected to the pipe-shaped, protruding area 39a by means of the sealing cap 100.

This means that the sealing cap 100 has a first cylindrical section 101 whose diameter is somewhat larger than the internal diameter of the pipe-shaped, protruding area 39a and a second cylindrical section 102 whose diameter is the same as the external diameter of the pipe-shaped, protruding area 39a. Two through holes 103 and 104 extending in the axial direction are located in the center of the sealing cap 100.

In addition, a bell-shaped cover piece 200, in which the motor cooling outlet pipe 7 and the motor cooling inlet pipe 8 are located as a unit, is provided for the pipe-shaped, protruding area 39a. The pipes 7 and 8 are attached to the base area 201 by a weld, so that the motor cooling outlet pipe 7 and the motor cooling water inlet pipe 8 penetrate the base area 201 of the cover piece 200. One end of the pipe 7 is in contact with the through hole 103 of the sealing cap 100, and one end of the pipe 8 is in contact with the through hole 104, and the pipes are pressed in, making use of the elasticity of the sealing cap 100, and fixed in place.

A flange-shaped section 202 (a section in the form of a flat plate) is found on the lateral face of the opening side of the cover piece 200. The cylindrical piece 39c, which exhibits a flange-shaped section 39b, is likewise attached to the outer perimeter of the pipe-shaped, protruding area 39a, matching the flange-shaped area 202. The flange-shaped areas 202 and 39b are attached to each other by screws 203, by means of which the cover piece 200 is flush with the pipe-shaped, protruding area 39a.

The permeable pipe 300 consists of a cylindrical section whose one end is open and whose other end is closed. The wall of the permeable pipe 300 has numerous holes 301. A built-on connection piece 302 at one end of the permeable pipe 300 is press-fitted to the sealing cap 100 and attached to it, so that the built-on connection piece 302 is in contact with the through hole 304 of the sealing cap 100. The permeable pipe 300 has, for example, a length L1 of 150 mm, an internal diameter of 12 mm and an external diameter of 14 mm. The external diameter of the built-on connection piece 302 measures 6 mm. Each of the holes 302 of the permeable pipe 300 has a diameter of 3 mm. Pipe 300 has a total

of twenty holes 301, forming a row of five holes in the axial direction of the permeable pipe 300 and a row of four holes along its periphery.

The heat storage pipe 5 of the embodiment is shaped as shown in Figure 17 such that covers 51 and 52, made of brass, are connected by solder joints to the opposing ends of a hollow cylindrical pipe made of brass.

[column 13] The heat storage pipe 5, for example, has a length L2 of 140 mm, a wall thickness of 0.2 mm, and an external diameter of 20 mm. A silver solder with excellent corrosion resistance to $Ba(OH)_2 \cdot 8H_2O$ is used for the soldering. A tapped hole 11b for a pipe made of PT1/8 is made in the covering 52, a ball 10 8 mm in diameter is inserted through the tapped hole 11b, and the screw cap 11 is screwed into the tapped hole 11b.

As shown in Figure 16, the dimensions of the heat accumulator 1 are, for example, as follows: the width H2 of the outer container 3 is 172 mm, while its diameter is 112 mm; the width H1 of the inner container 2 is 150 mm and its diameter 100 mm. The internal diameter of the pipe-shaped, protruding area 39a measures 22 mm. As shown in Figure 18A, the thermal insulation container 39 is filled with nineteen storage pipes 5.

The external diameter of both the motor cooling water outlet pipe 7 and the motor cooling water inlet pipe 8 measures 6 mm, and the diameter of each through hole 303 and 304 of the sealing cap 100 measures 5 mm. The sealing cap 100 is made of silicone rubber. In this case, the internal diameter of the pipe-shaped, protruding area 39a of the thermal insulation container 39 is made as small as possible while yet permitting insertion of the heat storage pipe 5. Missing Figure

With a heat accumulator of the design described above, the hot water conveyed from the motor 25 (see Figure 4) flows through the motor cooling water inlet pipe 8 into the permeable pipe 300 through the through hole 104 of the sealing cap 100; the hot water in the permeable pipe 300 then flows out of its holes 301. The hot water is put in circulation around the heat storage pipes 5 in the thermal insulation container 39, exchanges heat with the heat storage medium 9 in the heat storage pipes 5, flows through the through hole 103 of the sealing cap 100 and the motor cooling water outlet pipe 7, and comes out to the side of the motor 25 (see Figure 4).

A procedure for assembly of the heat accumulator of this embodiment is described below with reference to Figures 19 and 20.

The thermal insulation container 39 is arranged as shown in Figure 19A such that the pipe-shaped, protruding area 39a is located in its upper part, and a heat storage pipe 5 is inserted from the pipe-shaped, protruding area 39a. As shown in Figure 17, the underside of the cover 51 of the heat storage pipe 5 is flat and runs lengthwise along the heat storage pipe 5 under a right angle. The external diameter of the heat storage pipe 5 measures 20 mm, so that the heat storage pipe 5 rests in a stable position on the flat base of the thermal insulation container 39.

As shown in Figure 19B, the heat storage pipe 5 is moved bit by

bit to the side of the thermal insulation container 39 by means of a rod 400. Through repetition of this procedure, six or seven heat storage pipes 5 (there are heat storage pipes 5 that are not shown in the drawing) are inserted in the thermal insulation container 39 as shown in Figure 19C. There are small gaps between the heat storage pipes 5, since in this case the pipes 5 are moved only by the rod 400. The thermal insulation container

[column 14] 39 is set down on its side as shown in Figure 20A and turned in the direction of the arrow R in the drawing, whereby the crack is made as small as possible and the heat storage pipes 5 are arranged in a tightly packed manner.

As shown in Figure 20B, the thermal insulation container 39 is again arranged such that the pipe-shaped, protruding area 39a is located in the upper part, the heat storage pipes 5 are inserted in the thermal insulation container 39, and the empty area of the thermal insulation container 39 is filled with heat storage pipes 5, with the pipes being moved by means of the rod 400. The procedures shown in Figures 20A and 20B are repeated as needed, and in this way the thermal insulation container 39 is filled with heat storage pipes 5 to the highest possible density. Filling to the highest possible density means a state in which the thermal insulation container 39 with a permeable pipe 300 inside is filled with as many heat storage pipes 5 as possible in accordance with the representation in Figure 18A.

As shown in Figure 20C, when the permeable pipe 300 is inserted in a force fit and fastened to the through hole 104, then the sealing cap 100 is inserted in a force fit and fastened to the pipe-shaped, protruding area 39a of the thermal insulation container 39. As shown in Figure 20D, the cover piece 200 is arranged so as to form one continuous unit with the motor cooling water outlet pipe 7 and the motor cooling water inlet pipe 8 on the second cylindrical section 102 of the sealing cap 100. Upon pressing one end of the motor cooling water outlet pipe 7 on the through hole 103 of the sealing cap 100 and one end of the motor cooling water inlet pipe 8 on the through hole 104, the flange sections 39b and 202 are fastened to each other with screws 203, by means of which the cover piece 200 is mounted on the pipe-shaped, protruding area 39b of the thermal insulation container 39.

Results from tests to determine the solidification/dissolution characteristic lines of the heat storage medium 9 in the heat accumulator 1 of the embodiment are described below with reference to Figures 16 to 21.

The diagram in Figure 21 shows the changes in temperature (indicated by a solid line in Figure 21) of the heat storage medium 9 and the hot water temperature (indicated by a broken line in Figure 21) in the motor cooling water inlet pipe 8 when hot water at about 80°C to 95°C is put into circulation in the heat accumulator 1 for about 33 minutes and then water at about 25°C is put into circulation in the heat accumulator 1 for 8 minutes.

A thermostatic device whose temperature can be selectively adjusted is used as the hot water supply source. The temperature

of the thermostatic device is set at 95°C, the inlet and the outlet of the thermostatic device are connected to the outlet pipe 7 and the inlet pipe 8, respectively, of the heat accumulator 1 with agitator, and hot water is put into circulation in the thermostatic device and in the heat accumulator 1. The temperature of the hot water in the motor cooling water inlet pipe 8 is gradually raised from an initial temperature of 80°C and attains 95°C in the diagram of Figure 21. This is because the temperature measurement begins at the time when the temperature of the hot water of the thermostatic device reads approximately 80°C.

When the hot water at 95°C is cooled to water at 25°C,

[column 15] the inlet and the outlet of the thermostatic device are detached from the outlet pipe 7 and the inlet pipe 8, respectively, of the heat accumulator 1, and process water (25°C) is fed from the motor cooling water inlet pipe 8 at a flow rate of 4.5 l/min. and the water from the motor cooling water outlet pipe 7 is discharged.

As shown by the diagram, by inducing the hot water at 95°C to circulate in the thermostatic device of the heat accumulator 1 for roughly 30 minutes, the heat storage medium 9 absorbs heat from the hot water, stores latent heat, and is completely liquefied. When water is fed at about 25°C to the heat accumulator 1 at a time when the heat storage medium 9 is liquefied, the heat storage medium 9 transfers latent heat to the water and completely solidifies.

The rapid liquefaction and rapid solidification properties are suitable for a quick-acting heater in a motor vehicle. Since the inventor has confirmed that it is highly desirable for the heat to be emitted within about 5 minutes after the motor is started, the embodiment described above fulfills the existing requirement.

The effects of this embodiment are described below.

In the first embodiment, with utilization, for example, of the cooling water collector 6 as shown in Figure 18B, and with the internal diameter of the thermal insulation container 39 measuring 100 mm, the external diameter of the heat storage pipe 5 measuring 20 mm and the thickness of the cooling water collector 6 measuring 1 mm, the thermal insulation container can be filled with 14 heat storage pipes 5, so that the filling ratio of the heat storage medium 9 for the volume within the thermal insulation container 39 is 56%.

With utilization of the permeable pipe 300 with an external diameter of 14 mm instead of the cooling water collector 6 in this embodiment, as shown in Figure 18A, the thermal insulation container 39 can be filled with 19 heat storage pipes 5, so that the filling ratio is 77%. Thus the heat storage pipes 5 can be more efficiently accommodated in the thermal insulation container 39 with the eleventh embodiment.

In the event that the filling ratio of the heat storage medium 9 for a heat accumulator is fixed beforehand, the number of heat storage pipes 5 must necessarily be determined on the basis of the predetermined filling ratio. Since the heat storage pipes 5 in

the thermal insulation container 39 can be more effectively accommodated in the embodiment, the internal volume of the thermal insulation container 39 for accommodation of the requisite number of heat storage pipes 5 can be smaller; consequently, the heat accumulator can be made smaller.

When the motor cooling water outlet pipe 7 and the motor cooling water inlet pipe 8 are placed at different sites in the thermal insulation container 39, two openings (the pipe-shaped, protruding area 39a in the embodiment) are needed for the thermal insulation container 39 in order to connect the interior and the exterior. Each of the openings must have a cross-sectional area that is large enough to permit easy insertion of the storage pipe 5.

[column 16] The embodiment has only one opening - a pipe-shaped, protruding area 39a; and the opening made by the pipe-shaped, protruding area 39a has a cross-sectional area large enough to permit easy insertion of the heat storage pipe 5. It is generally known that the heat retention characteristics improve when the number of openings is smaller and the cross-sectional area of the opening is smaller, so that this embodiment can improve the heat retention characteristics relative to the first embodiment, in which the thermal insulation container 39 has two openings.

The thermal insulation container 39 is constructed by means of welding. With the embodiment which utilizes a pipe-shaped, protruding area 39a of the thermal insulation container 39, the number of welds made at the time the thermal insulation container 39 is manufactured is small, so that the thermal insulation container 39 can be manufactured inexpensively.

With the heat exchanger in which the thermal insulation container 39 has a pipe-shaped, protruding area 39a, utilization of the permeable pipe 300 permits the motor cooling water to be put into circulation in the thermal insulation container 39, and the heat storage medium 9 in the thermal insulation container 39 can exchange heat with the motor cooling water.

Although $Ba(OH)_2 \cdot 8H_2O$ is used as heat storage medium 9 in the preceding embodiments, $Mg(NO_3)_2 \cdot 6H_2O$, which has a melting point of 89°C and a latent heat of fusion of 38 cal/g, or similar substances can also be used.

The invention is not limited to implementation for a quick-acting heater in a motor vehicle, but can also be applied to a quick-acting heater for use in a house or similar application, such as a hot water supply device.

Although the heat storage pipe 5 is pipe-shaped, the invention is not limited to this shape; an oval shape may also be used.

Although the invention has been described exclusively in connection with its preferred embodiment and with reference to the attached drawings, it should be noted that a person skilled in the art would recognize the possibilities for numerous changes and modifications. Such changes or modifications are to be understood as falling under the purview of the invention as defined by its claims.

Patent Claims

1. A heating device comprising:
a heat storage medium (9) that contains a salt hydrate that induces no supercooling and which can undergo a reversible change between a liquid phase and a solid phase in conjunction with the absorption and emission of latent heat;
a heat storage container (5) that is made of a thermally conductive material and contains the heat storage medium (9);
an agitator (10, 29-38, 40, 45, 46) to agitate the heat storage medium (9) in the heat storage container (5); a heat transfer medium [column 17] for exchange of heat with the heat storage medium (9) in the heat storage container (5); a thermal insulation container (39) that contains the heat storage container (5) and the heat transfer medium for exchange of heat with the heat storage container (5), where the thermal insulation container (2, 3, 4) contains a thermal insulation material (4) to insulate external heat from the heat storage container (2, 3, 4) and the heat transfer medium;
and
a heat accumulator (1) with an inlet (8) and an outlet (7), which is connected to the thermal insulation container (39), so that the heat transfer medium can flow into the thermal insulation container (39) through the inlet (8) and so that the heat transfer medium can flow out of the thermal insulation container through the outlet (8).

2. Heating device according to claim 1, where the agitator (10, 29-38, 40, 45, 46) contains a ball (10), which is movable within the heat storage container (5), in order to agitate the heat storage medium (9).

3. Heating device according to claim 1, where the agitator (10, 29-38, 40, 45, 46) contains drives (29-37, 40, 45, 46) that are located outside of the heat storage container (5) in order to displace or move the heat storage container (5).

4. Heating device according to claim 1, which also includes a source of vibration (30, 32);
where the agitator (10, 29-38, 40, 45, 46) contains an elastic support device (29, 37) for elastic support of the heat storage container (5) and/or the thermal insulation container (39);
and
where the heat storage container (5) and/or the thermal insulation container (39) is/are arranged such that the vibration source (30, 32) can be induced to set up vibrations in it/them via the elastic support device (29, 37).

5. Heating device according to claim 1 which also contains:
a number of additional heat storage containers (5) and a number of additional agitators (10);
where the heat storage container (5) and each additional heat storage container (5) is a pipe-shaped element with mutually opposing sealed ends, which contain(s) an agitator (10) or a number of additional agitators (10).

6. Heating device according to claim 1, where:
the thermal insulation container (39) has a pipe-shaped element (39a), one end of which takes in the heat transfer medium through

the inlet (8);
a wall of the pipe-shaped element (39a) has an array of holes through it; and
the heat transfer medium flows from the pipe-shaped element (39a) through the holes into the thermal insulation container (39).

7. Heating device according to claim 1, where the thermal insulation container (39) has a single opening (39a) through which the interior of the thermal insulation container (39) communicates with its exterior; and the inlet (8) and the outlet (7) communicate with the opening (39a).

[column 18] 8. Heating device according to claim 1, where the agitator (10, 29-38, 40, 45, 46) serves to agitate the heat storage medium (9) when the heat storage medium (9) is liquefied.

9. Heating device according to claim 1 that also contains:
a hot water supply source (25) to supply hot water that serves as heat transfer medium;
a thermal radiator (14) that exchanges the heat of hot water carried from the heat accumulator (25) with air in the area around the radiator (14) to heat the air;
where the inlet (8), the hot water supply source (25), the thermal insulation container (39), the thermal radiator (14) and the outlet (7) form a first circuit through which the hot water can circulate; and
the inlet (8), the thermal insulation container (39), the thermal radiator (14) and the outlet (7) form a second circuit through which the hot water can flow.

10. Heating device according to claim 9, where:
the hot water is the motor cooling water and the hot water supply source (25) is a motor vehicle engine;
and
the thermal radiator (14) is a heating unit to heat the passenger compartment of a vehicle.

11. Process for exchange of heat with a coolant, where the process includes the following steps:
Conveyance of the coolant alongside a container (5) that contains a heat storage medium (9) which can transfer latent heat to the coolant when the heat storage medium (9) undergoes a reversible phase change between a liquid phase and a solid phase, and which can absorb latent heat from the coolant when the heat storage medium (9) undergoes a reversible phase change between the solid phase and the liquid phase;
Transfer of heat from the heat storage medium (9) to the coolant when the coolant is at a temperature below that of the heat storage medium (9);
Transfer of heat from the coolant to the storage medium (9) when the coolant is at a temperature sufficient for the heat storage medium (9) to undergo a phase change from the solid phase to the liquid phase; and
Agitation of the heat storage medium (9) during the step in which heat is transferred from the heat storage medium (9) to the coolant.

12. Process according to claim 11, where the step involving

agitation includes a step to create a flow of heat storage medium (9) within the container (5) so as to stop the growth of unmelted, heat-resistant crystals in the heat storage medium (9).

13. Process according to claim 11, where the step involving agitation includes a step to create a flow of heat storage medium (9) within the container (5) so as to prevent or delay the growth of unmelted, heat-resistant crystals in the heat storage medium (9).

14. Process according to claim 11, where the step

[column 19] involving agitation includes a step to move a movable element (10) within the container (5) to agitate the heat storage medium (9).

15. Process according to claim 14, where the step involving movement includes a step to shift the position of the container (5) so as to move the element (10) in the container (5).

16. Process according to claim 11, where the step involving agitation includes a step to move the container (5) by means of the hydrodynamic force of the coolant so as to agitate the heat storage medium (9).

17. Process according to claim 11, where the step involving agitation includes a step to move the container (5) by means of the vibrational force of a motor-driven drive shaft (32) so as to agitate the heat storage medium.

13 pages of drawings attached

[Key to 1st page of drawings (Figures 1-3)]

1. Drawings, page 1
2. Number:
   Int. Cl.[5]:
   Disclosure date:
3. DE 196 19 810 A1
   F 28 D 20/00
   November 21, 1996
4. Figure 1
5. Outflow
6. Coolant
7. Influx

[Key to 2nd page of drawings (Figure 4)]

1. Regulator

[Key to 3rd page of drawings (Figures 5 and 6)]

1. Coolant temperature (°C)
2. 16 minutes
3. Heat capacity of brass pipe
4. Time (minutes)
5. Pipe
6. Soluble components
7. Insoluble components

[Key to last page of drawings (Figure 21)]

1. Coolant temperature (°C)
2. Heat capacity of brass pipe
3. Time (minutes)